

INVESTIGATING CARBON PARTITIONING AND PROCESS MODELLING IN THE GARDEN OF EDEN. FINDINGS THROUGH 2006

Robert Powers and Jianwei Zhang, PSW Research Station

Grants obtained through SCIFMRC as supplemented by Sierra Pacific Industries afforded the following accomplishments in 2006:

1. Biomass estimation equations for boles, branches and foliage for plantation trees through age 15.
2. Estimates of leaf area index (LAI) for three of the plantations.
3. Estimates of forest floor mass for three plantations.
4. Estimates of fine root biomass (those less than 5 mm diameter) for three plantations.
5. Instrumentation for continuous measurements of soil moisture to a depth of 100 cm in three plantations and meteorological data for each site.
6. Pilot trial for estimating continuous water use by plantation trees.
7. Preliminary tests of the 3-PG simulator for one of the plantations.

Work supported by these funds centers on three Garden of Eden plantations that span the full range of site qualities in the study (Elkhorn, Whitmore, and Feather Falls in order of ascending productivity). These accomplishments are highlighted below.

Biomass Estimation Equations. Previously, five of the Garden of Eden plantations (Chester, Feather Falls, Jaws, Pondosa, Whitmore) were thinned from below. Only those treatments receiving Insecticide (HI, HFI) were thinned, and only at the point that trees were developing appreciable inter-tree competition as determined by changes in height-diameter trends. Insecticide treatments had no discernable effect in the experiment, and thinning only the "I" treatments allowed us to maintain three replicates of H and HF treatments in an unthinned condition for future comparisons of thinning vs no thinning. Thinning removed half of the trees, leaving the 10 best-formed trees per each measurement plot. Of trees felled in thinning, two well-formed trees of smaller and larger size classes were sectioned in each plot for biomass analysis, providing the basis for biomass estimation equations based upon DBH or DBH x Height. As of this writing, only those equations developed from the Whitmore thinnings have been completed. These were applied to Whitmore stand data to estimate standing biomass at age 15 years for the unthinned C, F, H, and HF treatments (Fig. 1). Equations from Whitmore and the other four plantations will be compared to see if site-specific equations are necessary, or if equations can be developed that apply universally.

Leaf Area Index Relationships. We estimated LAI in each replicate C, F, H, and HF treatments in the Elkhorn, Feather Falls and Whitmore plantations. Correlations between current LAI and current stand basal area and/or crown cover allowed us to estimate LAI for past years. Comparing X-Y pairs of LAI vs standing volume (Fig. 2) indicates that LAI correlates closely with stand production in young plantations. Furthermore, the

trend is unaffected by site quality or treatment. As LAI improves with site quality or treatment, production increases in a predictable fashion.

Tree Biomass at 15 Years, Whitmore Garden of Eden

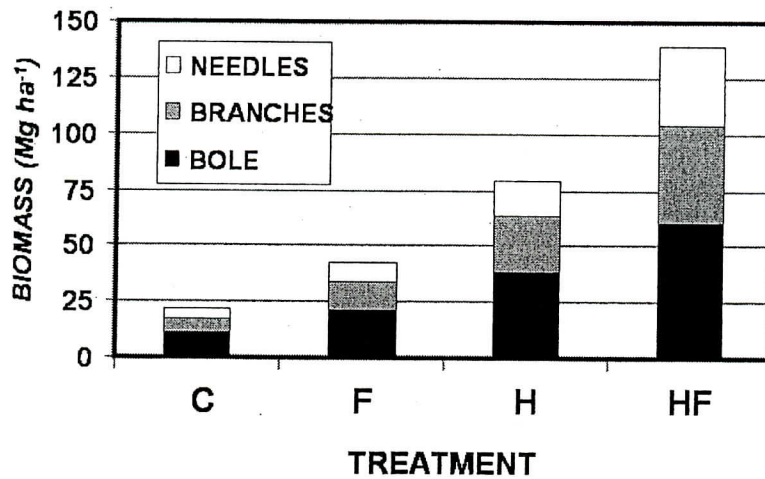


Figure 1. Partitioned standing biomass in planted trees at age 15 for the Whitmore Garden of Eden plantation for Control (C), Fertilized (F), Herbicide (H), and combined (HF) treatments.

LEAF AREA INDEX AND STAND VOLUME LARGELY INDEPENDENT OF SITE QUALITY

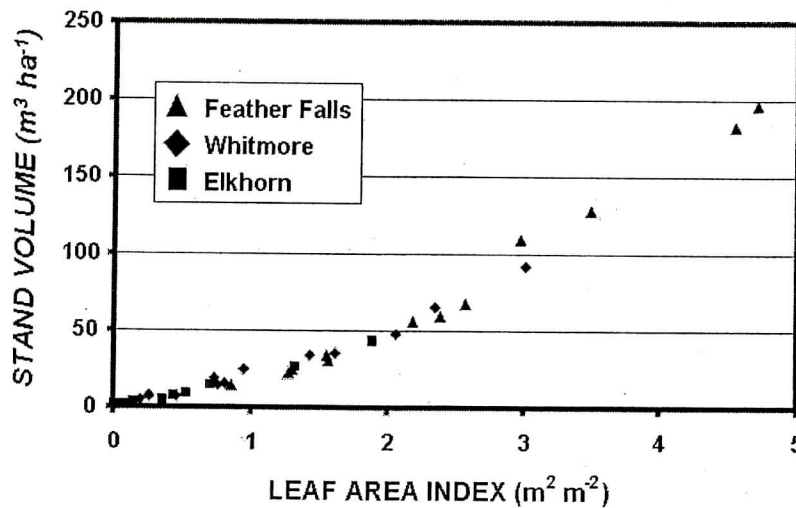


Figure 2. Relationship between LAI and standing volume for three Garden of Eden plantations. All treatments are combined.

Forest Floor Mass. Using 0.25 m² frames we collected all litter accumulated in the forest floor for C, F, H, and HF treatments at Whitmore (2005) and Elkhorn and Feather Falls (2006) when the plantations had achieved about 2 decades of growth. Such data are useful in estimating the mass of carbon and other nutrients sequestered in litter as affected by treatment and site quality. Net forest floor mass (the amount remaining after decomposition) increased with site quality (Elkhorn the least, Feather Falls the most) and increased with treatments promoting tree growth, most notably fertilization (*Fig. 3*). Similarities between Whitmore and the more productive Feather Falls undoubtedly reflect enhanced decomposition of the forest floor at Feather Falls. Each sample was separated further into woody and foliage components and by pine or shrub origin (not shown). At Whitmore and Feather Falls, forest floor mass was identical between C and H treatments, meaning that the lack of litter from a shrub understory was balanced by increased inputs from pine litter.

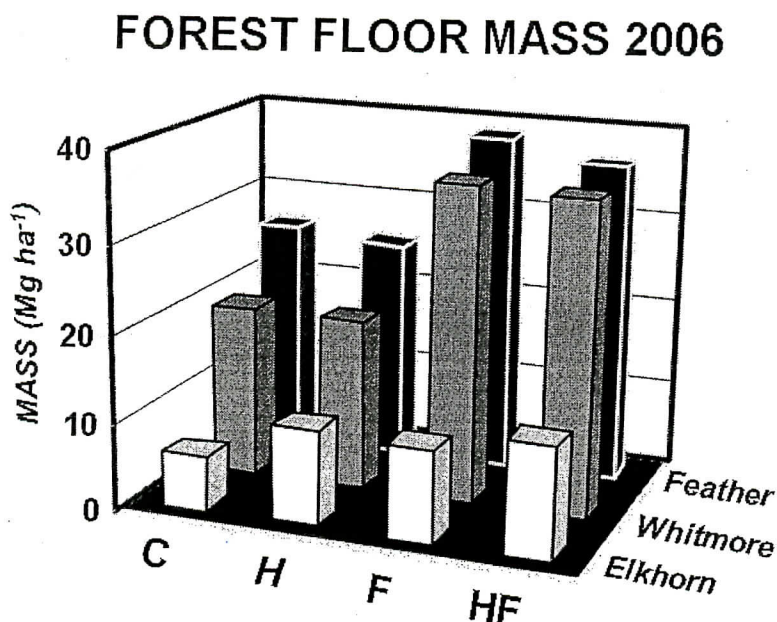


Figure 3. Effect of treatment and site on net forest floor mass present after 2 decades of plantation development.

Fine Root Sampling. Using a specialized soil auger, soils were sampled at Elkhorn, Whitmore, and Feather Falls plantations in 2005 and 2006 at depths of 0-15, 15-30, 30-60, and 60-92 cm. Fine roots (generally those less than 5 mm diameter) were separated from soil and analyzed for biomass and nutrient content. The residual mineral soil was also analyzed for nutrient content. Fine root biomass for Whitmore (the only analyses completed as of this writing) indicates that treatments improving tree growth also increased fine root production (*Fig. 4*). We believe that decomposition of fine roots is the primary pathway for increasing soil organic matter and the storage of organic carbon in the mineral soil.

FINE ROOT BIOMASS AT WHITMORE

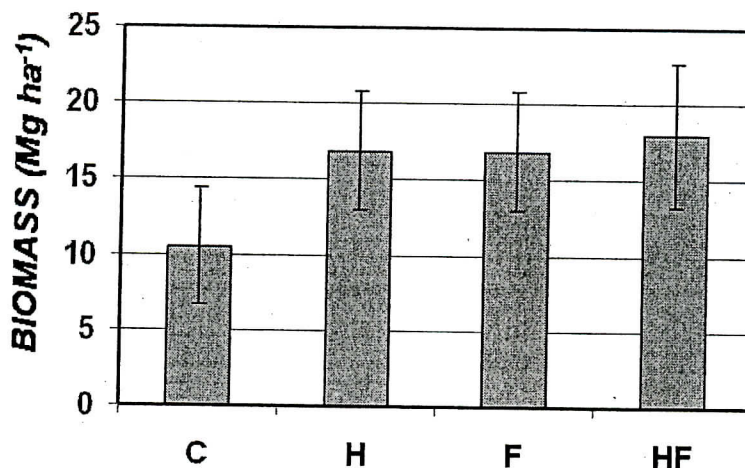


Figure 4. Fine root biomass in relation to treatment at Whitmore as sampled in 2005. Vertical bars represent one standard error of the mean.

Instrumentation and Estimates of Water Use. Along with continuously recording meteorological stations, dataloggers and sensors were installed in 2006 at the Elkhorn, Feather Falls, and Whitmore Garden of Eden plantations. This allowed us to monitor soil water flux in the C, H, F, and HF treatments to a depth of 1 m. Whitmore also was instrumented for estimating water use using sapflow rate technology. This allowed us to estimate transpiration rate for each treatment through the course of the growing season (Fig. 5). Transpiration rate tracked closely with climatic conditions, especially vapor pressure deficit (VPD) and solar radiation (R_n) as recorded by our meteorological stations (Fig. 6). Trends for the extreme treatments at Whitmore are shown in Figs. 5 and 6 for the 2006 growing season.

Early in the growing season when soil water was abundant and VPD was low (May), transpiration rates were similar for trees in HF and C plots treatments even though trees on C plots carried much less leaf area than those on HF plots. When VPD and R_n increased and available soil water was still high in July, 2006, HF trees transpired much more water than Control trees. Significant reduction of transpiration coincided with the heat wave occurring in July 2006. Soil water supply could not meet transpirational demand, so trees closed their stomata in avoiding cavitation. High transpiration rates resumed when soil moisture had been replenished by capillary action from surrounding soil and from deeper in the soil profile. By August, high transpiration rates in the HF treatment had depleted soil moisture sufficiently that transpiration rates in the HF treatments were less than those in the C treatments where trees had less leaf area. We conclude that rapidly-growing HF trees will experience high water stress first. Our findings are supported by independent $\delta^{13}\text{C}$ analyses of pine foliage collected on the site over several years of plantation development (Horwath and Powers, unpublished). These data allow us to estimate how much water is available for the plants and when trees stop

growing due to water stress. A quick check of transpirational loss of soil water prorated across an entire year shows that losses at Whitmore are equivalent to total precipitation.

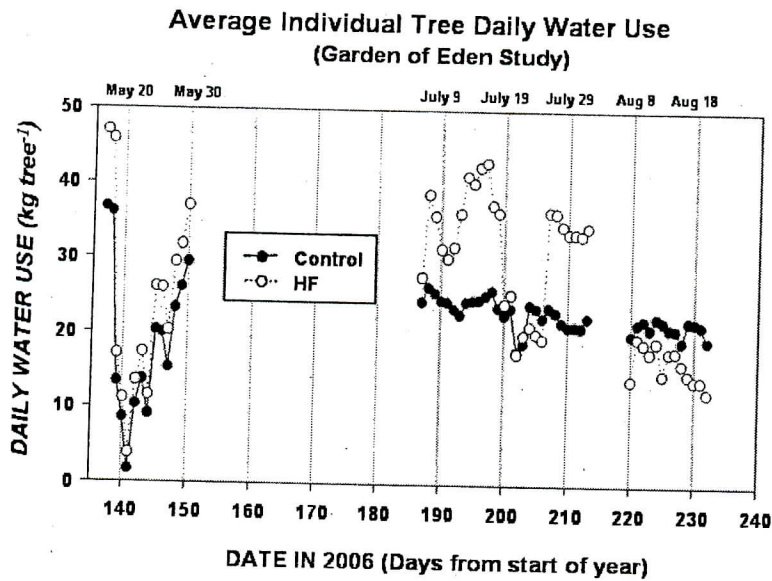


Figure 5. Sapflow analysis of daily water use by individual trees in the Control and HF treatments at Whitmore. Gaps in the data indicate either battery failure or the relocation of instruments in another study. Assuming an annual rate of water use of ~20 kg per tree per day, inflow in precipitation is entirely transpired.

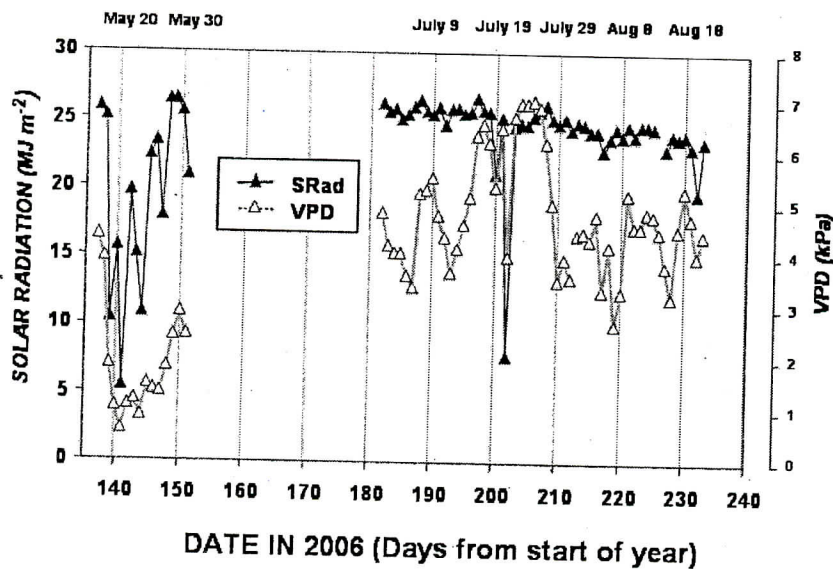


Figure 6. Trends in R_n and VPD at the Whitmore Garden of Eden plantation during the 2006 growing season. Trends in VPD correlate with trends in daily water use by trees (*Fig. 5*).

Preliminary Tests of 3-PG. Variables described above are critical for tuning some parameters in 3-PG (Physiological Principles Predicting Growth) model as we have proposed previously. Whitmore data for the first 20 years (1986 – 2006) were employed for our first 3-PG run. We used Whitmore because we have the most detailed climatic data at that site from 1990 to present. Although there are several assumptions that need to be tested in the future, we found that model behaved exceptionally well (*Fig. 7*), and we couldn't resist extrapolating 3-PG projections to age 50 for the Whitmore Garden of Eden. We recognize that these projections are strictly speculative and rest on certain assumptions of future climate. Therefore, we look forward to collecting full-growing season data and carbon allocation data in 2007 through destructive sampling above and below ground. We will test all of our assumptions before recommending 3-PG for general use predicting ponderosa pine behavior across northern California sites.

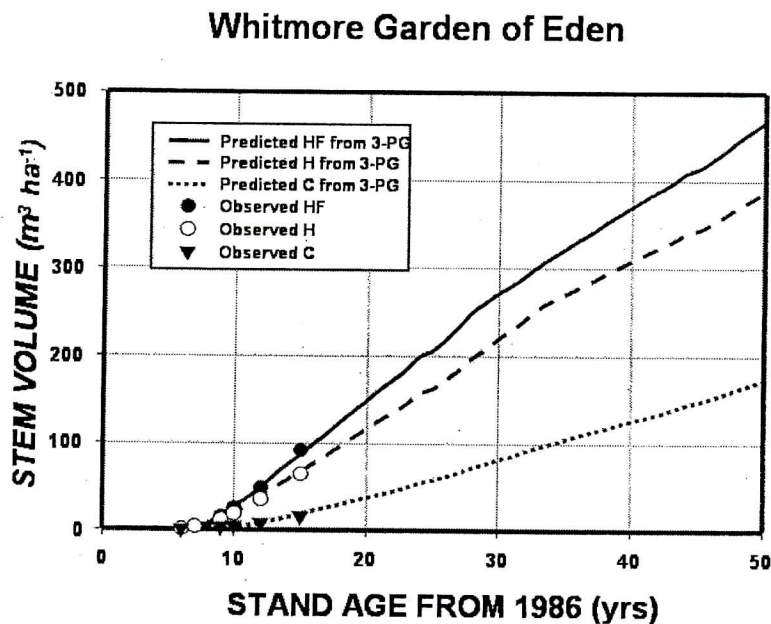


Figure 6. Measured changes in cumulative stand volumes at the Whitmore Garden of Eden plantation for three silvicultural treatments (circles and triangles). 3-PG estimates from climatic and physiological data are shown by the trend lines and extrapolated to age 50 years.